PRECISION IN ARTERIAL WALL THICKNESS MEASUREMENT USING ULTRASONIC IMAGING

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ABSTRACT

Quantitative assessment of intima media thickness (IMT) of the carotid artery using ultrasound has become a standard method for cardiovascular diagnostics. Standard methodology is of crucial importance in reducing uncertainty. We have applied five methods to 20 subjects in a reproducibility study. The methods involve differences in anatomical alignment, visual enhancement and the use of mechanical aid. Ultrasound images in two different body positions were acquired twice within two weeks for 20 subjects using the ATL UM-4 ultrasound system. The results on IMT image acquisition were analyzed from quantitative IMT measurement. The use of a mechanical rotator was found to have the most significant effect, which points to the importance of further development work in this direction.

INTRODUCTION

B-mode ultrasonic imaging of arterial wall thickening has evolved from qualitative visualization to quantitative assessment over the last 10 years. Intima media thickness (IMT)[1] is now being used in cardiovascular diagnostics and, in particular, epidemiologic studies. Improvement in the precision of IMT would mean that a smaller sample size is needed and would reduce the cost in such studies[2,3]. It is generally believed that the main determinant of ultrasound uncertainty arises from human error. The factors include the lack of instrumentation control, body positioning alignment and sonography transducer control. While better machines, proper anatomical alignment and transducer control have improved the overall reproducibility. The lack of standardization and less than optimum protocol have limited these improvements.

The quality of IMT images and reproducibility of the IMT measurements are highly dependent on the anatomical position, instrumentation control, and the ultrasonographer. Performance of the ultrasonographer is an important component of IMT measurement reproducibility in population-based studies as well as clinical trials[4]. Given the potential for variation from study site to study site, multicenter studies in particular will require consistent high quality standardized B-mode images of IMT. Reproducible imaging of the exact same carotid arterial wall site under the same conditions in each individual over time is absolutely vital to the integrity of any longitudinal clinical IMT study or yearly vascular IMT examination[6].

We have used 20 subjects to test several standardization protocol and measured the resulting precision. This forms the basis for establishing an optimum method for IMT measurements.

INSTRUMENT STANDARDIZATION

When ultrasound images are diagnosed by visual inspection, the operator may try to optimize the output by adjusting controls such as power, gain, depth and frame rate. For quantitative IMT measurements, such manual adjustments can result in a systematic readjustment and introduce extraneous shift. IMT measurement of the carotid artery ranges from 0.49 to 2.00 mm and changes of the order of 0.02 mm are detectable[3]. Any deviation of these ultrasound machine control can impact measurement change. It is important that a standard setting be established for a machine and sonographers be properly trained to comply with the usage of standard protocol.

Figure 1. Split-Screen method.

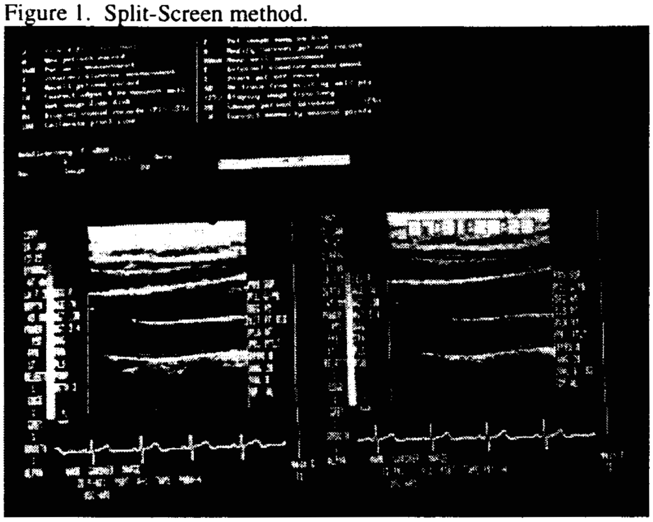

Figure 2. Rotation device.

VISUAL ENHANCEMENT

We have used a standard anatomical position to test the improvement due to some visual aid to the sonographer. The subjects lie supine with their head turned 45°. We call this standard procedure method 0. The first visual aid we tested is to have a hard-copy of an image from a previous scan available to the sonographer who will try to match the new image with the hard-copy (method 1). This results in improved reproducibility. There is a further slight improvement when the baseline image is displayed on a split screen during the repeat scan with stacking (method 2) as shown in Figure 1. In method 2, a real-time display system is used whereby the baseline image is brought up onto one half of the screen of the ultrasound monitor so that the ultrasonographer can observe the baseline and the real-time repeat image simultaneously in a split screen view. The first method incurs the slight cost of a hard copy and the split-screen method involves a one-time programming cost. Both methods lessen sonographer time in searching for an appropriate image. There is compelling reason to adopt these methods in the standard protocol.

MECHANICAL ROTATION

The IMT measurements were taken from a longitudinal view of the artery. For an accurate measurement the ultrasonic beam has to be perpendicular to the arterial wall. This is achieved by first taking a transverse view and then rotating the transducer by 90°. Whereas if done manually, the perpendicular ultrasonic beam to the arterial wall would be difficult to obtain. We have designed a mechanical rotation device (as shown in Figure 2) that allows the sonographer to turn the transducer to the correct position. This device works well in a manual mode in which the operator maintains position of the device with one hand and rotates the transducer within the collar with the other hand. A motorized version of the rotator is currently in progress. A mechanical rotation device not only holds the transducer in a reproducible angle at each examination, but it also reproducibly rotates the transducer 90° around the central axis without angulation error or azimuth changes in the probe angle, while maintaining the jugular vein stacked above the carotid artery[5]. Positioning the transducer in the stacked carotid/jugular transverse view defines a unique angle perpendicular to the carotid artery diameter and a similarly unique longitudinal view if the transducer is rotated precisely 90°. Avoiding angulation errors and azimuth changes while rotating the transducer free-hand is impossible, and use of the mechanical rotation device may account for much of the improvement in variability.

ANATOMICAL POSITION STANDARDIZATION

The usage and understanding of the anatomical plane of the human body are essential for patient positioning. Exterior positioning can be easily controlled with the patient's head angle aligned with the body sagital plane. By controlling the external positioning, the variation of acquiring the interior vascular anatomy is reduced. We have tried a slight modification of the standard method by implementing stacking (parallel alignment of the jugular vein and the common carotid artery)[5]. The result is a very slight improvement in correlation.

We believe that the commonly used supine position with the subject's head turned 45° is not the optimal position for detecting change in replicate scanning of the common carotid artery. The main reason for this belief is that with the subject's head turned, the carotid artery becomes slightly twisted, and so to replicate the exact degree of twist is difficult. The use of head pillows and facial and head landmarks help to establish the exterior positioning but not the internal twisting. We have hypothesized that a supine position with the head in-line anatomic position will facilitate better IMT measurement reproducibility.

Anatomical reference is also an essential key point in obtaining precision in IMT measurement for reproducibility. The common site for IMT measurement is referenced to the common bulb and the distal common carotid artery. The IMT measurement is measured at 0.25 centimeter from the proximal bulb. Therefore, the accuracy of image acquisition of the common bulb needs to be clearly identified. Thus, the procedure in obtaining the anatomical reference must be well defined in the standard protocol.

RESULTS

We have scanned 20 subjects twice using each of the five methods and compared the reproducibility of the two trials. The result is summarized in Table 1. The left half of the table refers to a computer analysis based on a single frame out of two cardiac cycles. The correlation between the two trials for all five methods is excellent, ranging from 0.945 to 0.994. The correlation of variance (CV) shows a progressive improvement in the five methods. Viewing both images side-by-side on the split screen reduces IMT variability by 12% when compared with using a hard copy of the baseline image (CV reduced from 3.25 to 2.87) for single frame IMT analysis. However, for 4 frame IMT measurement averaging, the IMT variability is reduced by 21% (CV reduced from 2.39% to 1.88%). See Table 1.

Table 1. Summary of ultrasound image acquisition methods.

	Single Frame IMT					Four Frame Average IMT				
Method	0	1	2	3	3a	0	1	2	3	3A
45 Degree	X	X	X	X		X	X	X	X	
Lateral					X					X
Hard-copy		X					X			
Split Screen			X	X	X			X	X	X
Stacking			X	X	X			X	X	X
Rotator				X	X				X	X
Correlation	0.945	0.981	0.985	0.996	0.994	0.972	0.987	0.992	0.996	0.999
CV (%)	3.84	3.25	2.87	1.60	1.40	3.16	2.39	1.88	1.32	0.58
MAD (mm)	0.026	0.022	0.021	0.013	0.0095	0.024	0.017	0.014	0.0098	0.0041

The lateral positioning (method 3a) further improved carotid IMT measurement reproducibility by 56% (CV reduced to 0.58%) for 4 frame averaging compared with the 45° head turning position (Table 1). For comparison purposes and a summary of their improvement in carotid IMT measurement reproducibility due to our advancements in positioning techniques and methodologies, the total data are presented in Table 1. Method 0 is the most commonly used positioning method for acquiring carotid IMT images. Although this method also produces a 45° head turn positioning, it does not provide the usage of a baseline image for repeat scan comparison, or stacking, or the use of a mechanical transducer holding device.

CONCLUSION

We have used the 45° head turn position without a baseline image or stacking of the jugular vein and carotid artery (method 0) as a basis to gauge the improvement of the other methods. There is an increase in reproducibility when a hard copy image is used for the repeat scan (method 1). This reproducibility is increased further when the baseline image is displayed on a split-screen during the repeat scan with stacking (method 2). In the 45° head turn position, use of the baseline/on-line split-screen image, with stacking, and with the use of the mechanical rotation device (method 3) yielded the greatest reproducibility. The best result occurs in the anatomic head in-line position with the transducer laterally placed (method 3a). In all cases the use of 4 frame IMT averaging instead of a single frame improves the variability. The change that makes the most impact is the use of the mechanical rotator. Further validation study and improvement of the mechanical device is indicated.

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REFERENCES

1. Pignoli, P., Tremoli, E., and Poli, A.: Intimal plus medial thickness of the arterial wall: a direct measurement with ultrasound imaging. Circulation, 74 (1986) 1399.

2. Bond, M.G., Barnes, R.W., Riley. W.A. et al.: High resolution B-mode ultrasound scanning methods in the atherosclerosis Risk in Communities study (ARIC), J. Neruoimaging, 1 (1991) 68.

3. Selzer, R.H., Hodis, H.N., Kwong-Fu, H., et al.: Evaluation of computerized edge tracking for quantifying intima-media thickness of the common carotid artery from B-mode ultrasound images, Atherosclerosis, (1994) 111:1-11.

4. Perrson, J., Stavenow, L., Wikstrand, J., Israelsson, B., Formgren, J. and Berglund, G.: Noninvasive quantification of atherosclerotic lesions. Reproducibility of ultrasonographic measurement of arterial wall thickness and plaque size, Arteriosclerosis Thromb., 12 (1992) 261.

5. Beach, K.W., Issac, C.A., Phillips, D.J., Strandness, D.E.: An ultrasonic measurement of superficial femoral artery wall thickness. Ultrasound Med. Biol., (1989) 15:723-728.

6. Hodis, H.N., Mack, W.J., LaBree, L., Selzer, R.H., et al.: Reduction in Carotid Arterial Wall Thickness Using Lovastatin and Dietary Therapy. Annals of Internal Medicine, 124 (1996) 6:548-556.